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A Final Report to
THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
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COSMIC X-RAY PHYSICS

For the Period: 1 January 1985 - 31 March 1992

From

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I. THE SOFT X-RAY BACKGROUND

From 1985 through 1987, the major work on the soft x-ray background involved the analysis of the data obtained from sounding rocket 17.020, launched from White Sands, NM in May 1984, and from sounding rocket 27.103, launched from White Sands in February 1986. Jeff Bloch and Mike Juda received their Ph.D. degrees in January 1988 based on their work on these two sounding rocket flights and analysis of the data obtained.

In late 1987 Steve Snowden began to work with the scientific staff of the Max-Planck Institut in preparation for using the data from the upcoming German X-ray astronomy satellite, ROSAT, to help in the analysis of our sounding rocket sky survey data. During a six-month period in late 1988, his salary support was provided by the Max-Planck Institut.

Snowden, Cox, McCammon and Sanders have made substantial progress toward the completion of a paper interpreting the sky survey B band count rate as an indicator of the extent of a cavity in the local interstellar medium.

Juda continued working on the limits on absorbing material within the local cavity.

Bloch, now at Los Alamos, continued to work on limits on the iron line emission at 72 eV present in the diffuse background. New calibration results of Brad Edwards have softened the conclusions somewhat and the final analysis is still pending. Interim results were presented in a poster at IAU Colloquium 115, "High Resolution X-Ray Spectroscopy of Cosmic Plasmas," in Cambridge, MA on 22-25 August 1988.

Zhang also attended IAU Colloquium 115, and presented a paper on "Observing Soft X-ray Line Emission from the Interstellar Medium with X-ray Calorimeter on a Sounding Rocket," with UW co-authors Juda, Edwards and McCammon.

In 1989 Steve Snowden continued to work with the scientific staff of the Max-Planck Institut in preparation for using the data from the upcoming German X-ray astronomy satellite, ROSAT, to help in the analysis of our sounding rocket sky survey data.

Snowden, Cox, McCammon and Sanders have completed and submitted to the Astrophysical Journal a paper interpreting the sky survey B band count rate as an indicator of the extent of a cavity in the local interstellar medium.

McCammon and Sanders completed and submitted an article for the Annual Reviews of Astronomy and Astrophysics on "The Soft X-ray Background and Its Origins."

Juda, following up on his Ph. D. thesis research, continued working on the limits on absorbing material within the local cavity.

Edwards, as part of his Ph. D. thesis, has almost completed his analysis of our most recent (6 December 1988) sounding rocket flight. He has found that there is at least one direction on the sky, towards galactic coordinates (132, -69), where the ratio of the Be band count rate to the B band count rate differs from the value found in other parts of the sky. He interprets this as possibly due to absorption of the soft x-ray background by an intervening interstellar cloud. His spectral analysis of the Be band data found poor agreement between the measured pulse height distribution and that predicted to be emitted

from a hot plasma in ionization equilibrium with solar abundances of the elements. Better agreement with the observed data was obtained when the abundance of iron in the model was reduced.

For the first part of the year 1990, Steve Snowden continued his work with the scientific staff of the Max-Planck Institut in preparation for using the data from the German X-ray astronomy satellite, ROSAT, to help in the analysis of our sounding rocket sky survey data. On 1 June 1990, ROSAT was launched, and Snowden began work with the Max-Planck staff on the reduction and preliminary analysis of the ROSAT sky survey data.

Mike Juda, following up on his Ph. D. thesis research, which involved the analysis of our May 1984 and February 1986 sounding rocket flights (17.020 and 27.103), completed his work on the limits on absorbing material within the local cavity which will be published in the Astrophysical Journal in 1991. He found that for a model in which the bulk of the observed soft X-ray emission originates in a uniform low-density region surrounding the Sun, the 2-sigma upper limit on the HI column density over an average path through the local emitting region is $7.8 \times 10^{19} \text{ cm}^{-2}$. If the average path length is $\sim 100 \text{ pc}$, then clouds similar to the one in which the Sun is embedded (density $\sim 0.1 \text{ cm}^{-3}$) could still have a filling factor as large as 25%.

Brad Edwards, completed his Ph. D. thesis, which included his analysis of our most recent (6 December 1988) sounding rocket flight. He found that there is at least one direction on the sky, towards galactic coordinates (132° , -69°), where the ratio of the Be band count rate to the B band count rate differs from the value found in other parts of the sky. He interprets this as possibly due to absorption of the soft x-ray background by an intervening interstellar cloud. These results were presented by Edwards et al. at the AAS meeting in January in Washington, DC.

Edwards' spectral analysis of the Be band data found poor agreement between the measured pulse height distribution and that predicted to be emitted from a hot plasma in ionization equilibrium with solar abundances of the elements. Better agreement with the observed data was obtained when the abundance of iron in the model was reduced.

II. PROPORTIONAL COUNTER AND FILTER CALIBRATIONS

In 1988 Edwards completed construction and testing of a vacuum chamber for use on the Aladdin electron storage ring located 20 miles from Madison. The chamber is large enough to hold one detector from our UXT sounding rocket payload and also contains two eight-position filter wheels. We obtained the use of a storage ring synchrotron beam port and soft x-ray monochromator for three weeks in October. We obtained high signal-to-noise measurements of the pulse height response to monochromatic low energy x-ray lines for two of the three UXT flight detectors. The goal of these measurements was to better understand the response of the detectors in the neighborhood of the 72-eV Fe lines. The transmissions of some each of the new and old flight filters were also measured for several low energy x-ray lines.

In 1989 Edwards completed analysis of the data he had collected the previous year at the Aladdin electron storage ring. These data consisted of high signal-to-noise measurements of the pulse height response to monochromatic low energy x-ray lines for two of the three UXT sounding rocket flight detectors. These measurements led to a better understanding of the response of the UXT detectors, especially in the neighborhood of the 72-eV Fe lines. The measurements of the x-ray transmissions of some of the flight filters also aided in the understanding of the detector response.

III. SOUNDING ROCKET FLIGHT PREPARATIONS

Following the successful first flight of the UXT payload, on sounding rocket 17.020 in May 1984, as a piggy-back on the Bragg Crystal Spectrometer payload, preparations were made to reflly the UXT payload as a stand-alone experiment. This process took a little longer than usual for a "reflight" because the payload was reconfigured for UXT alone, and the management of the sounding rocket was handed off from Goddard/Greenbelt to Goddard/Wallops. In the fall of 1985, the refurbished payload was taken to the Wallops Flight Facility for test and integration by Juda and Sanders. In January the payload team, Juda, Snowden and McCammon, went to White Sands and the rocket was launched on 1986 February 1 at UT 0540. Post-flight calibrations were the responsibility of Juda and occupied much of the remainder of 1986.

In late 1987, preparations were begun for the reflight of the UXT payload as sounding rocket 27.121. Test and integration took place at the Wallops Flight Facility of the Goddard Space Flight Center in the fall of 1988. The integration team was Juda, Skinner and Sanders. A successful launch and recovery took place at the White Sands Missile Range in December 1988. The first two flights of this payload revealed that the Be band count rate is proportional to the B band count rate, with very little scatter, for fifteen northern galactic hemisphere targets. The targets for this third UXT flight were all in the southern galactic hemisphere: the Eridanus soft x-ray enhancement, several targets near the galactic plane, and several targets at intermediate-to-high southern galactic latitude, including the 21-cm cloud associated with absorption-like features in the B and C bands by Burrows et al. (1984).

IV. NEW SOUNDING ROCKET PAYLOAD: X-RAY CALORIMETER

From 1985 through 1988, much work, lead by Zhang, Juda and McCammon, was done on the development of new high spectral resolution cryogenic x-ray detectors and on the design of a new sounding rocket payload to study the soft x-ray background using these detectors.

In 1988 much progress was made on the detailed mechanical analysis of the flight cryostat. We have successfully grown ferric ammonium alum crystals directly on wires and inside a support tube, to be able to make a very low-mass salt pill assembly with a high filling factor of active salt and good thermal contact to the wires.

We completed the first run of aluminum beam suspended detectors and find that the thermal performance of the beams is better than we had expected. Detectors mounted on four short (equal length and width) beams of 6000 Å thick aluminum (1% Si) show a thermal conductivity of 3×10^{-11} Watts/Kelvin at 100 mK. This implies an effective phonon mean free path of only a few times the thickness of the beams--about the right value for completely diffuse boundary scattering. In all other materials that we've measured specular scattering dominates the diffuse scattering by the time you get down to this temperature. The low conductivity of the aluminum beams may be due to some other effect, perhaps related to the fact that the thickness of the beams is less than the average phonon wavelength (about 1 micron).

In 1989 we have successfully grown an iron alum crystalline salt pill suitable for the flight adiabatic demagnetization refrigerator (ADR). We intend to go ahead and make a spare while the undergraduates who did the work are still around. Details of the cryostat design are being completed, and we have a workable design for the thermal housings for the FETs. Extensive tests have been made of aluminum to fiberglass-epoxy glue joints at temperatures down to 77 K. We have developed a process for making joints that are reliably stronger than the composite, and therefore feel confident that we can use a simplified construction employing glued joints.

A great deal of effort has gone into screening various varieties of FETs for the preamp. The best we have found so far are NJ-14ALs from Interfet, which have noise levels around $2.5 \text{ nV}/\sqrt{\text{Hz}}$ and corner frequencies below 10 Hz. They will not operate satisfactorily below 110 K, however, and must be run with V_{dg} below 2 volts to stay below the I_{g} breakpoint where current noise increases rapidly.

The aluminum beam supported calorimeters we have been fabricating have just the right thermal conductivity through the Al supports, but have a serious problem in that most of the energy in an X-ray pulse goes into a very long tail with a decay time exceeding 30 ms (for a detector with a thermal decay time, C/G, of 1 ms). Our current thinking is that this is due to quasiparticle formation in the Al beams, but it is not clear why the fraction of the energy tied up this way should be so large. We hope to get back to the physics of this before too long, but for the time being are working with the all-silicon devices being produced at Goddard. One of these (with a HgTe absorber) has achieved 11 eV FWHM energy resolution for 6 keV X-rays, and 8 eV at low energies.

In 1990 progress was made in the mechanical and thermal designs of the sounding rocket payload, particularly the cryostat design. The mechanical design involved modeling the ADR as a system of three damped springs and four masses. The first spring system connects the rocket skin and the the ADR. The second spring system is between the vacuum jacket of ADR and the liquid helium can and consists of two G-10 cylindrical shells. The third spring system is the Kevlar fibers which connect the helium can to the cold stage. Using the finite element analysis method, we calculated the displacement and stress distribution, and the resonant frequencies.

Several mechanical tests were performed. We tested the shear strength of the Armstrong Epoxy A-12, which is used to make joints

between aluminum and G-10, and we tested the tensile strength of the Kevlar 49 fiber.

The thermal design involved constructing and running a thermal model of the ADR to determine its thermal properties. In the ADR, we plan to use two radiation shields and multilayer insulation (crinkled aluminized mylar) outside shields. The calculations are done using the "SPICE" in-circuit emulator program running on a main-frame computer located at the Physical Sciences Laboratory in Stoughton, Wisconsin. Associated with the thermal design effort was determining the emissivity and conductivity appropriate at low temperature for the materials used in the ADR. The efficiency of the vapor cooling is the least well-determined factor in the whole thermal design, and after reviewing the available literature, we made a special dewar to measure the efficiency. The results were submitted for publication to RSI and will appear in 1991.

Juda continued his efforts to refine the processing techniques for making thin calorimeters suitable for the sounding rocket payload, and well as work on techniques for making more advanced detectors that would be suitable for large-format imaging arrays.

A paper was presented by Juda et al. at the Albuquerque AAS meeting in June describing the current design of the sounding rocket payload.

V. THEORETICAL STUDIES

From 1985 through 1987, the major work in the theoretical studies involved following up the thesis work of Edgar, modeling the soft x-ray background as the product of a single supernova blast wave, and pursuing the thesis work of Boulares and Slavin as described below.

In late 1988 Boulares completed a several part Ph.D. thesis, receiving his degree in December. The topics include a paper with Cox on possible cosmic ray acceleration in the Cygnus Loop, a useful decomposition of the cosmic ray electron spectrum, an analysis of the hydrostatics of the ISM perpendicular to the galactic disk, and a piece on the pitfalls of being too naive about the ISM when studying the galactic gravitational potential.

Slavin revised his paper on cloud evaporation and it has been accepted for publication by the Ap. J. He has also developed a 1D hydro code coupled to our ionization rate and cooling rate codes to follow the late time evolution of supernova remnants, the time dependence of thermal evaporation of clouds, and a number of other exciting applications.

Cox worked with both Boulares and Slavin on their projects, in addition pushing forward in his efforts to develop a global picture of the diffuse ISM.

During this period, he concentrated on preparing a paper for the EUV Astronomy meeting in Berkeley showing the dramatic effects of an interstellar magnetic field on the evolution of supernova remnants.

The principal thrust of the theory effort during 1989 was completing work on the code for studying supernova remnant evolution in diffuse media, deciding on the significant observables to calculate,

and reviewing the observational information on the diffuse interstellar conditions in which the explosions would occur.

A preliminary paper on the surprises in store for the supernova remnant evolution was presented by Cox and Slavin at the Berkeley EUVE meeting in January. The diffuse ISM review and the effects that the new SNR evolution results have on our understanding of the medium were presented in invited reviews at Granada (IAU Colloquium No. 120) in the spring and the Tetons (2nd Wyoming ISM Conference) in July. The Granada paper also presented new ideas on the ionization mechanism and ionization structure of the medium, while the Tetons paper discussed the disturbing coincidence between the rates of supernovae and cloud heating.

The picture we have of the diffuse ISM is being altered dramatically as a consequence of recent observational studies and the theoretical effort we are supplying to draw them into focus. The medium is characterised by a much larger role for diffuse warm gas, with a very large scale height and significantly larger nonthermal pressure than previously appreciated. This strongly affects our understanding of galactic formations, superbubble evolution, high stage ions, magnetic field generations, and the general pervasiveness of hot gas in the medium.

On other fronts, the group effort to elaborate a clear description of the Local Bubble culminated in the submission of the Snowden et al. paper. The hydrostatics paper of Boulares and Cox was withdrawn from Ap. J. and underwent substantial revision in response to the rapidly developing observational constraints. It was then resubmitted and appeared in the Ap. J. in 1990.

A new graduate student, Warren Miller, was started on a project to determine the theoretical pattern of the diffuse ISM ionization structure due to OB stars in the solar neighborhood.

Progress seemed painfully slow but there were so many careful details to be concerned with. It is good now to be past that period, with results in hand and many new exciting applications for the codes we have developed.

In 1990 the picture we have of the diffuse ISM is being altered dramatically as a consequence of recent observational studies and the theoretical effort we are supplying to draw them into focus. The medium is characterised by a much larger role for diffuse warm gas, with a very large scale height and significantly larger nonthermal pressure than previously appreciated. This strongly affects our understanding of galactic formations, superbubble evolution, high stage ions, magnetic field generations, and the general pervasiveness of hot gas in the medium.

Jon Slavin finished his thesis on diffuse gas in the interstellar medium - studies involving coupled ionization, radiation and dynamics. The first part, which was published in the Astrophysical Journal in 1989, is a study of the consequences of a conductive boundary on the Local Cloud, the warm ($T \sim 8000$ K), low density ($n \sim 0.1 - 0.2 \text{ cm}^{-3}$) region immediately surrounding the Sun. The second part presents the results of a one-dimensional (spherically symmetric) numerical simulation of the evolution of a supernova remnant in a homogeneous medium with a $5 \mu\text{Gauss}$ magnetic field and a density of 0.2 cm^{-3} . He found that the evolution of the remnant, once it has become radiative,

differs in several significant ways from that predicted for the equivalent field-free case. Most importantly the hot bubble in the interior occupies only a small fraction of the shocked volume, the remainder in a thick shell of slightly compressed material.

Warren Miller, continued his work on a project to determine the theoretical pattern of the diffuse ISM ionization structure due to OB stars in the solar neighborhood.

Edgar continued his efforts in modeling individual and multiple supernova explosions to simulate the formation of the Local Bubble and to compare the resulting x-ray spectra with soft x-ray background data. Work was begun on efforts to incorporate into the plasma modeling programs the effects of dust destruction, non-Maxwellian velocity distributions, and magnetic fields. He also collaborated with Savage and others in the Astronomy department in studies of interstellar Al III away from the galactic plane, and of molecules in the plane towards the Gum Nebula.

Cox presented a paper on the characteristics of the diffuse interstellar medium at IAU Symposium No. 147 in Grenoble, and in Leiden at IAU Symposium No. 144, he presented his current ideas relating the hot gas of the disk and the hot gas of the halo. He spent the fall semester in Saclay, France as a Visiting Professor of Astrophysics at the Centre d'Etudes Nuclaires. While there he learned more about interstellar magnetic fields and presented several colloquia and seminars on the diffuse interstellar medium.

Note that the ending date for this grant was 31 December 1990, but in March of 1991, a one-year no-cost extension was granted, extending the formal life of the grant until 31 March 1992. However, the grant funds were exhausted at the end of August 1991, so this report only covers activities until then.

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January 1, 1988 to December 31, 1990

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- "Thermal Detection of X-rays," McCammon, D., Edwards, B., Juda, M., Plucinsky, P., Zhang, J., Kelley, R., Holt, S., Madejski, G., Moseley, S. H., and Szymkowiak, A. 1990, in Low Temperature Detectors for Neutrinos and Dark Matter III (Gran Sasso, L'Aquila, Italy, 20-23 September 1989), eds. Brogiato, L., Camin, D. V., and Fiorini, E. (Gif sur Yvette: edition Frontieres), p. 213.
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- "Cryogenic Microcalorimeters for High Resolution Spectroscopy: Current Status and Future Prospects", McCammon, D., Cui, W., Juda, M., Plucinsky, P., Zhang, J., Kelley, R. L., Holt, S. S., Madejski, G. M., Moseley, S. H., and Szymkowiak, A. E. 1990, Nuclear Physics A527, in press (M.I.T., 25-29 June 1990).

INVITED TALKS

- "X-Rays from the Galactic Halo," Cox, D. P. 1985, Greenbank Workshop on Gaseous Haloes of Galaxies, National Radio Astronomy Observatory, Greenbank, West Virginia, May 30-June 1, 1985.
- "Calorimetric Detectors," McCammon, D. 1985, Miniworkshop on Low Temperature Detectors, Swiss Institute for Nuclear Research, Villigen, Switzerland, 13 December 1985.
- "Performance Characteristics of a Bolometer for Energy Analysis of Hard X-rays," McCammon, D. 1987, Workshop on PEP as a Synchrotron Radiation Source, 20-21 October 1987, Stanford, CA.
- "High Resolution Microcalorimeters and Tunnel Junction Detectors," McCammon, D. 1988, Spring Meeting of the American Physical Society, 18 - 21 April 1988, Baltimore, Md.
- "Energy Input into the Interstellar Medium", Cox, D. P. 1989, 2nd Wyoming Conference on the Interstellar Medium, Grand Tetons, WY, July 1989.

CONTRIBUTED TALKS

- "Development of a Quantum Calorimeter for X-ray Spectroscopy", R. L. Kelley, J. C. Mather, S. H. Moseley, R. F. Mushotzky, McCammon, D., and A. E. Szymkowiak, 165th Meeting of the A.A.S., Tucson, Arizona, January 1985.
- "Ultrasoft X-ray Background Observations Toward the North Galactic Pole," J. J. Bloch, K. Jahoda, M. Juda, D. McCammon, W. T. Sanders, and S. L. Snowden, 165th Meeting of the A.A.S., Tucson, Arizona, January 1985.
- "Galactic HI at High Latitudes," F. J. Lockman, K. M. Jahoda, and D. McCammon, Greenbank Workshop on Gaseous Haloes of Galaxies, NRAO, Greenbank, West Virginia, May 1985.
- "Galactic HI in Directions of Low Total Column Density," F. J. Lockman, K. M. Jahoda, and D. McCammon, 166th Meeting of the AAS, Charlottesville, Virginia, June 1985.
- "Observations of the Soft X-ray Diffuse Background Below 0.2 keV," M. Juda, J. J. Bloch, D. McCammon, W. T. Sanders, and S. L. Snowden, 170th Meeting of the AAS, Vancouver, BC, June 1987.

- "Possible Absorption of the Diffuse X-ray Background by a Nearby Interstellar Cloud," Edwards, B. E., Juda, M., McCammon, D., Plucinsky, P., Sanders, W., and Zhang, J. 1990, 175th Meeting of the AAS, Washington, D.C., January 1990.
- "X-ray Quantum Calorimeter (XQC): A Sounding Rocket Instrument for High Spectral Resolution Studies of the ISM," Juda, M., Cui, W., McCammon, D., Plucinsky, P., Snedeker, C., Zhang, J., Kelley, R., Madejski, G., Moseley, H., Szymkowiak, A. 1990, 176th Meeting of the AAS, Albuquerque, New Mexico, 10-14 June 1990.
- "Non-Ohmic Conduction of Implanted Silicon and NTD Germanium," Zhang, J., Cui, W., Juda, M., McCammon, D., Plucinsky, P. P., Sanders, W. T., Snedeker, C., Kelley, R. L., Holt, S. S., Madejski, G., Moseley, S. H., and Szymkowiak, A. E. 1991, Berkeley Workshop on Semiconductor Thermistors for milliKelvin Operation (Berkeley, CA, 27 May 1991).
- "Thermal Detectors for Astrophysics," Juda, M., Cui, W., McCammon, D., Sanders, W. T., Snedeker, C., Zhang, J., Holt, S. S., Kelley, R., Madejski, G., Moseley, S. H., and Szymkowiak, A. E. 1991, 5th Pisa Meeting on Advanced Detectors: Frontier Detectors for Frontier Physics (Elba, 30 May 1991).

COLLOQUIA AND SEMINARS

- "A Thermal Microcalorimeter for High-Resolution Spectroscopy," McCammon, D. 1985, Guelph University, Physics Dept. Colloquium.
- "Experimental Tests of a Single-Photon Calorimeter for X-Ray Spectroscopy," McCammon, D. 1985, Fermilab Colloquium.
- "A Calorimetric Spectrometer for X-Ray Astronomy," McCammon, D. 1985, University of Wisconsin - Madison, Astronomy Dept. Colloquium.
- "Thermal Calorimetry for High-Resolution Spectroscopy," McCammon, D. 1985, Technical University of Munich, Physics Department Seminar.
- "X-Ray Astrophysics," McCammon, D. 1985, Swiss Institute for Nuclear Research.
- "A Thermal Solid State Detector for High-Resolution Spectroscopy," McCammon, D. 1985, IBM Watson Research Center Colloquium.
- "Supernova Remnants and the Interstellar Medium," Cox, D. P. 1985, Rice University, Astronomy and Space Physics Colloquium, March 1985
- "Current Ideas on Supernova Dominated Interstellar Media" Cox, D. P. 1986, Space Telescope Science Institute, Colloquium, May 1986, .
- "Aspects of Interstellar Cloud Stability," Cox, D. P. 1986, Madison Astronomy Colloquium, March 1986.
- "Theory of the Local Interstellar Medium," Cox, D. P. 1986, LISM Meeting, COSPAR, July 1986.
- "The Local Interstellar Medium," Cox, D. P. 1986, Harvard Astronomy Colloquium, December 1986.
- "High Resolution Thermal Calorimeters and their Application to X-ray Astronomy," McCammon, D. 1987, Bell Labs Physics Colloquium, March 3, Murray Hill, N. J.
- "Thermal Calorimeters for X-ray Astronomy: Current Status," McCammon, D. 1987, Institute for Space and Aeronautical Science Colloquium, Tokyo University, August 18, Tokyo.

- "Cryogenic Detectors," McCammon, D. 1987, joint Physics/Photon Factory Colloquium, KEK, 28 August 1987, Tsukuba City, Japan.
- "A Simple Model for the Diffuse X-ray Background," McCammon, D. 1987, Univ. of California Space Sciences Laboratory Colloquium, 23 October 1987, Berkeley, Calif.
- "Cryogenic Detectors for High Resolution Spectroscopy and Other Things," McCammon, D. 1987, North Carolina State Univ. Physics Dept. Colloquium, November 16, Raleigh, N.C.
- "Cosmic Ray Acceleration By Shocks," Cox, D. P. 1987, University of Wisconsin-Madison, Astronomy Department Colloquium, February 1987.
- "Supernova 1987a," Cox, D. P. 1987, University of Wisconsin-Madison, Physics Department Colloquium, September 1987.
- "Overview of the Interstellar Medium," Cox, D. P. 1987, University of Wisconsin-Madison Astronomy Department Colloquium, September 1987.
- "Overview of the Interstellar Medium," Cox, D. P. 1987, University of Rochester Astronomy Department Colloquium, October 1987.
- "Recent Results with High Resolution Cryogenic Calorimeters," McCammon, D. 1988, Milan University Physics Dept. and I.N.F.N. Colloquium, 7 October 1988, Milan.
- "Thermal Microcalorimeters for High Resolution Spectroscopy," D. McCammon, National Research Council of Canada Physics Colloquium, 7 July 1988, Ottawa, Ontario.
- "Application of Cosmic Ray Shock Theories to the Cygnus Loop," A. Boulares, Santa Fe Conference, September 1988, Santa Fe, New Mexico.
- "Supernova Remnants and the Nature of the Cosmic Ray Electron Spectrum," A. Boulares, Santa Fe Conference, September 1988, Santa Fe, New Mexico.
- "Reduction of Oort Limit and the Contribution of Dark Matter to It," A. Boulares, Santa Fe Conference, September 1988, Santa Fe, New Mexico.
- "Thermal Microcalorimeters for High Resolution Spectroscopy," Purdue University Physics Department Colloquium, 3 November 1988, West Lafayette, Ind.
- "The Galactic Diffuse X-ray Background and the Small Scale Organization of the Interstellar Medium," D. McCammon, Univ. of Virginia Astronomy/National Radio Astronomy Observatory Colloquium, 23 March 1989, Charlottesville, VA.
- "Progress and Problems in Understanding the Interstellar Medium," D. P. Cox, University of California Santa Cruz Astronomy Colloquium, January 1989.
- D. P. Cox, U. Wisconsin Plasma Seminar, September 1989.
- D. P. Cox, Ohio State University Astronomy Colloquium, October 1989.
- D. P. Cox, U. Wisconsin Astronomy Colloquium, Fall Semester 1989.
- "Spectroscopic Observations of the Soft X-ray Diffuse Background," W. T. Sanders, U. Wisconsin Astronomy Colloquium, 17 October 1989.
- "Observations of the Hot Interstellar Medium," W. T. Sanders, Los Alamos National Laboratory Astrophysics Seminar, 27 October 1989.
- "Soft X-rays from Interstellar Space," W. T. Sanders, U. Wisconsin Meteorology Colloquium, 30 October 1989.
- D. P. Cox, North Carolina State Physics Colloquium, November 1989.
- D. P. Cox, Rice University, Space Physics Colloquium, December 1989.
- "Current Status of our Understanding of the Diffuse Interstellar Medium," D. P. Cox, Service d' Astrophysique, Saclay, France, October 1990.
- "The Diffuse Interstellar Medium", D. P. Cox, Institut d' Astrophysique, Paris, France, November 1990.

- "What Have We Learned from X-ray Astronomy?" McCammon, D. 1991, University of California, Riverside, Physics Department Colloquium, 21 March, Riverside, Calif.
- "The Diffuse X-ray Background: How Much is Extragalactic?" McCammon, D. 1991, University of California, Berkeley, Astronomy Department Colloquium, 26 September, Berkeley, Calif.

PUBLIC SERVICE LECTURES

- "The Shape of Space," D. P. Cox, a lecture in a series for Rice Alumni, Rice University, October 1985.
- "The Shape of Space," D. P. Cox, an after dinner lecture at the annual banquet of Triangle Fraternity, University of Wisconsin-Madison, Spring 1986.
- "Supernova 1987a," D. P. Cox, Depts. of Physics and Astronomy Public Lecture, U.W. Spring 1987.
- "Supernova 1987a," D. P. Cox, Mathematics Department Seminar, University of Wisconsin, Spring 1987.
- "Supernova 1987a," D. P. Cox, WTSO Radio, Diana Summers talk show, Spring 1987.
- D. McCammon, Wisconsin State Science Symposium presentation (program for high school students), Madison, 2 March 1989.
- "Cryogenic Particle Detectors," D. McCammon, Talk for SPS - Zone 8 Meeting, Madison, 14 October 1989.
- D. McCammon, Assist with FET noise measurements for a Tracor Northern/ECE development project.
- "The Diffuse Interstellar Medium, Revisited", D. P. Cox, Madison Area Amateur Astronomers, March 1990.
- "X-ray Astronomy," D. McCammon, Wisconsin State Science Symposium presentation (program for high school students) 1 March 1990, Madison.
- D. McCammon, Presentations for Wisconsin Minority Undergraduate Recruitment Project, Campus Visitation Program; 15 & 16 November 1990.

Ph.D. THESES

Richard Edgar	August 1985	"The Soft X-ray Background as a Blast Wave Viewed from Inside"
Keith Jahoda	August 1986	"H I Structure and the Soft X-ray Background"
Jeff Bloch	January 1988	"Observations of the Soft X-ray Diffuse Background from 0.07-1.0 keV"
Mike Juda	January 1988	"Observations of the Diffuse X-ray Background Below 0.2 keV and Constraints on Simple Models for its Spatial Distribution"
Ahmed Boulares	December 1988	"High Energy Particles in Supernova Remnants and the interstellar Medium"
Brad Edwards	March 1990	"Possible Absorption of the Diffuse X-ray Background by a Nearby

Jonathan Slavin

June 1990

Interstellar Cloud"
"Diffuse Gas in the Interstellar
Medium: Studies Involving Coupled
Ionization, Radiation, and Dynamics"